Step 14 - Calculate the SCA for sections 1 through *n*, using MMD_n, η, ∊, E_{avg}, and p_e:

$$SCA_1 = -(\text{ç}/\text{å}) \times (1 - S_N) \times \ln(p_c)/(E_{avg}^2 \times MMD_1 \times 10^{-6})$$

$$\vdots$$

$$SCA_n = -(\text{ç}/\text{å}) \times (1 - S_N) \times \ln(p_c)/(E_{avg}^2 \times MMD_n \times 10^{-6})$$

where the factor 10^{-6} converts micrometers to meters. Note that the only quantity changing in these expressions is MMD_x; therefore, the following relation can be used:

$$SCA_{n+1} = SCA_n \text{ x } MMD_n/MMD_{n+1}$$

Step 15 – Calculate the total SCA and the English SCA, ESCA:

$$SCA\ (s/m) = \sum_{i=1}^{n} SCA_i$$

$$ESCA\ (ft^2/kacfm) = 5.080 \times SCA\ (s/m)$$

This sizing procedure works best for p_c values less than the value of LF, which means the smallest value of *n*. Any ESP model is sensitive to the values of particle diameter and electric field. This one shows the same sensitivity, but the expressions for electric field are based on theoretical and experimental values. The SCA should not be strongly affected by the number of sections chosen; if more sections are used, the SCA of each section is reduced.

6.2.1.3 Specific Collecting Area for Tubular Precipitators

The procedure given above is suitable for large plate-wire or flat plate ESPs, but must be used with restrictions for tubular ESPs. Values of $S_N = 0.015$ and RR = 0 are assumed, and only one section is used.

Table 6.5 gives migration velocities that can be used with equation 6.23 to calculate SCAs for several tubular ESP applications.

6.2.2 Flow Velocity

A precipitator collecting a dry particulate material runs a risk of nonrapping (continuous) reentrainment if the gas velocity becomes too large. This effect is independent of SCA and has been learned through experience. For fly, ash applications, the maximum acceptable velocity is about 1.5 m/s (5 ft/s) for plate-wire ESPs and about 1 m/s (3 ft/s) for flat plate ESPs. For low resistivity applications, design velocities of 3 ft/s or less are common to avoid nonrapping reentrainment. The frontal area of the ESP (W x H), *i.e.*, the area normal to the direction of gas flow, must be chosen to keep gas velocity low and to accommodate electrical requirements (*e.g.*, wire-to-plate spacing) while also ensuring that total plate area requirements are met. This area can be configured in a variety of ways. The plates can be short in height, long in the direction of flow, with several in parallel (making the width narrow). Or, the plates can be tall in height, short in the direction of flow, with many in parallel making the width large). After selecting a configuration, the gas velocity can be obtained by dividing the volume flow rate, Q, by the frontal area of the ESP:

$$v_{gas} = \frac{Q}{WH} \tag{6.24}$$

where:

v_{gas} = gas velocity (m/s)
W = width of ESP entrance (m)
H = height of ESP entrance (m)

When meeting the above restrictions, this value of velocity also ensures that turbulence is not strongly developed, thereby assisting in the capture of particles.

6.2.3 Pressure Drop Calculations

The pressure drop in an ESP is due to four main factors:

- Diffuser plate (usually present)—(perforated plate at the inlet)
- Transitions at the ESP inlet and outlet
- Collection plate baffles (stiffeners) or corrugations
- Drag of the flat collection plate

The total pressure drop is the sum of the individual pressure drops, but any one of these sources may dominate all other contributions to the pressure drop. Usually, the pressure drop is not a design-driving factor, but it needs to be maintained at an acceptably low value. Table 6.6 gives typical pressure drops for the four factors. The ESP pressure drop, usually less than about 0.5 in. H_2O, is much lower than for the associated collection system and ductwork. With the conveying velocities used for dust collected in ESPs, generally 4,000 ft/min or greater, system pressure drops are usually in the range of 2 to 10 in. H_2O, depending upon the ductwork length

Table 6.5: Tubular ESP Migration Velocities (cm/s)[b]

Particle Source		Design Efficiency, % 90	95
Cement kiln	(no BC)	2.2–5.4	2.1–5.1
	(BC)	1.1–2.7	1.0–2.6
Glass plant	(no BC)	1.4	1.3
	(BC)	0.7	0.7
Kraft-paper recovery boiler	(no BC)	4.7	4.4
Incinerator 15 μm MMD	(no BC)	40.8	39.
Wet, at 200°F MMD (μm)			
1		3.2	3.1
2		6.4	6.2
5		16.1	15.4
10		32.2	30.8
20		64.5	61.6

BC = Back corona

[a]These rates were calculated on the basis of:

S_N = 0.015, RR = 0, one section only.

These are in agreement with operating tubular ESPs; extension of results to more than one section is not recommended.

[b]To convert cm/s to ft/s, multiply cm/s by 0.0328.

and configuration as well as the type(s) of preconditioning devices(s) used upstream.

The four main factors contributing to pressure drop are described briefly below.

Table 6.6: Components of ESP Pressure Drop

Component	Typical Pressure Drop (in. H_2O)	
	Low	High
Diffuser	0.010	0.09
Inlet transition	0.07	0.14
Outlet transition	0.007	0.015
Baffles	0.0006	0.123
Collection plates	0.0003	0.008
Total	0.09	0.38

The diffuser plate is used to equalize the gas flow across the face of the ESP. It typically consists of a flat plate covered with round holes of 5 to 7 cm diameter (2 to 2.5 in.) having an open area of 50 to 65 percent of the total. Pressure drop is strongly dependent on the percent open area, but is almost independent of hole size.

The pressure drop due to gradual enlargement at the inlet is caused by the combined effects of flow separation and wall friction and is dependent on the shape of the enlargement. At the ESP exit, the pressure drop caused by a short, well-streamlined gradual contraction is small.

Baffles are installed on collection plates to shield the collected dust from the gas flow and to provide a stiffening effect to keep the plates aligned parallel to one another. The pressure drop due to the baffles depends on the number of baffles, their protrusion into the gas stream with respect to electrode-to-plate distance, and the gas velocity in the ESP.

The pressure drop of the flat collection plates is due to friction of the gas dragging along the flat surfaces and is so small compared to other factors that it may usually be neglected in engineering problems.

6.2.4 Particle Characteristics

Several particle characteristics are important for particle collection. It is generally assumed that the particles are spherical or spherical enough to be described by some equivalent spherical diameter.

Highly irregular or elongated particles may not behave in ways that can be easily described.

The first important characteristic is the mass of particles in the gas stream, *i.e.*, the particle loading. This quantity usually is determined by placing a filter in the gas stream, collecting a known volume of gas, and determining the weight gain of the filter. Because the ESP operates over a wide range of loadings as a constant efficiency device, the inlet loading will determine the outlet loading directly. If the loading becomes too high, the operation of the ESP will be altered, usually for the worse.

The second characteristic is the size distribution of the particles, often expressed as the cumulative mass less than a given particle size. The size distribution describes how many particles of a given size there are, which is important because ESP efficiency varies with particle size. In practical terms, an ESP will collect all particles larger than 1.0 μm in diameter better than ones smaller than 10 μm. Only if most of the mass in the particles is concentrated above 10 μm would the actual size distribution above 10 μm be needed.

In lieu of cumulative mass distributions, the size distribution is often described by log-normal parameters. That is, the size distribution appears as a probabilistic normal curve if the logarithm of particle size used is the abscissa. The two parameters needed to describe a log-normal distribution are the mass median (or mean) diameter and the geometric standard deviation.

The MMD is the diameter for which one-half of the particulate mass consists of smaller particles and one-half is larger (see the Procedure, Step 5, of Subsection 6.2.1.2). If the MMD of a distribution is larger than about 3 μm, the ESP will collect all particles larger than the MMD at least as well as a 3 μm particle, representing one-half the mass in the inlet size distribution.

The geometric standard deviation is the equivalent of the standard deviation of the normal distribution: It describes how broad the size distribution is. The geometric standard deviation is computed as the ratio of the diameter corresponding to 84 percent of the total cumulative mass to the MMD; it is always a number greater than 1. A distribution with particles of all the same size (monodisperse) has a geometric standard deviation of 1. Geometric standard deviations less than 2 represent rather narrow distributions. For combustion sources, the geometric standard deviations range from 3 to 5 and are commonly in the 3.5 to 4.5 range.

A geometric standard deviation of 4 to 5, coupled with an MMD of less than 5 μm, means that there is a substantial amount of submicrometer material. This situation may change the electrical conditions in an ESP by the phenomenon known as "space charge quenching", which results in high operating voltages but low currents. It is a sign of inadequate charging and reduces the theoretical efficiency of the ESP. This condition must be evaluated carefully to be sure of adequate design margins.

6.2.5 Gas Characteristics

The gas characteristics most needed for ESP design are the gas volume flow and the gas temperature. The volume flow, multiplied by the design SCA, gives the total plate area required for the ESP. If the volume flow is known at one temperature, it may be estimated at other temperatures by applying the ideal gas law. Temperature and volume uncertainties will outweigh inaccuracies of applying the ideal gas law.

The temperature of the gas directly affects the gas viscosity, which increases with temperature. Gas viscosity is affected to a lesser degree by the gas composition, particularly the water vapor content. In lieu of viscosity values for a particular gas composition, the viscosity for air may be used. Viscosity enters the calculation of SCA directly, as seen in Step 14 of the design procedure (page 6-33).

The gas temperature and composition can have a strong effect on the resistivity of the collected particulate material. Specifically, moisture and acid gas components may be chemisorbed on the particles in a sufficient amount to lower the intrimic resistivity dramatically (orders of magnitude). For other types of materials, there is almost no effect. Although it is not possible to treat resistivity here, the designer should be aware of the potential sensitivity of the size of the ESP to resistivity and the factors influencing it.

The choice of power supplies' size (current capacity and voltage) to be used with a particular application may be influenced by the gas characteristics. Certain applications produce gas whose density may vary significantly from typical combustion sources (density variation may result from temperature, pressure, and composition). Gas density affects corona starting voltages and voltages at which sparking will occur.

6.2.6 Cleaning

Cleaning the collected materials from the plates often is accomplished intermittently or continuously by rapping the plates severely with automatic hammers or pistons, usually along their top edges, except in the case of wet ESPs that use water. Rapping dislodges the material, which then falls down the length of the plate until it lands in a dust hopper. The dust characteristics, rapping intensity, and rapping frequency determine how much of the material is reentrained and how much reaches the hopper permanently.

For wet ESPs, consideration must be given to handling waste waters. For simple systems with innocuous dusts, water with particles collected by the ESP may be discharged from the ESP system to a solids-removing clarifier (either dedicated to the ESP or part of the plant wastewater treatment system) and then to final disposal. More complex systems may require skimming and sludge removal, clarification in dedicated equipment, pH adjustment, and/or treatment to remove dissolved-solids. Spray water from the ESP preconditioner may be treated separately from the water used to flood the ESP collecting plates, so that the cleaner of the two treated waters may be returned to the ESP. Recirculation of treated water to the ESP may approach 100 percent.

The hopper should be designed so that all the material in it slides to the very bottom, where it can be evacuated periodically, as the hopper becomes full. Dust is removed through a valve into a dust-handling system, such as a pneumatic conveyor. Hoppers often are supplied with auxiliary heat to prevent the formation of lumps or cakes and the subsequent blockage of the dust handling system.

6.2.7 Construction Features

The use of the term "plate-wire geometry" may be somewhat misleading. It could refer to three different types of discharge electrodes: weighted wires hung from a support structure at the top of the ESP, wire frames in which wires are strung tautly in a rigid support frame, or rigid electrodes constructed from a single piece of fabricated metal. In recent years, there has been a trend toward using wire frames or rigid discharge electrodes in place of weighted wire discharge electrodes (particularly in coal-fired boiler applications). This trend has been stimulated by the user's desire for increased ESP reliability. The wire frames and rigid electrodes are less prone to failure by breakage and are readily cleaned by impulse-type cleaning equipment.

Other differences in construction result from the choice of gas passage (flow lane) width or discharge electrode to collecting electrode spacing. Typically, discharge to collecting electrode spacing varies from 11 to 19 cm (4.3 to 7.5 in.). Having a large spacing between discharge and collecting electrodes allows higher electric fields to be used, which tends to improve dust collection. To generate larger electric fields, however, power supplies must produce higher operating voltages. Therefore, it is necessary to balance the cost savings achieved with larger electrode spacing against the higher cost of power supplies that produce higher operating voltages.

Most ESPs are constructed of mild steel. ESP shells are constructed typically of 3/16 or 1/4 in. mild steel, plate. Collecting electrodes are generally fabricated from lighter gauge mild steel. A thickness of 18 gauge is common, but it will vary with size and severity of application.

Wire discharge electrodes come in varied shapes from round to square or barbed. A diameter of 2.5 mm (0.1 in.) is common for weighted wires, but other shapes used have much larger effective diameters, *e.g.*, 64 mm (0.25 in.) square electrodes.

Stainless steel may be used for corrosive applications, but it is uncommon except in wet ESPs. Stainless steel discharge electrodes have been found to be prone to fatigue failure in dry ESPs with impact-type electrode cleaning systems.[3]

Precipitators used to collect sulfuric acid mist in sulfuric acid plants are constructed of steel, but the surfaces in contact with the acid mist are lead-lined. Precipitators used on paper mill black liquor recovery boilers are steam-jacketed. Of these two, recovery boilers have by far the larger number of ESP applications.

Table 6.7: Standard Options for Basic Equipment

Option	Cost adder (%)
1 - Inlet and outlet nozzles and diffuser plates	8 to 10
2 - Hopper auxiliaries/heaters, level detectors	8 to 10
3 - Weather enclosure and stair access	8 to 10
4 - Structural supports	5
5 - Insulation	8 to 10
Total options 1 to 5	1.37 to 1.45 × Base

6.3 Estimating Total Capital Investment

Total capital investment (TCI) for an ESP system includes costs for the ESP structure, the internals, rappers, power supply, auxiliary equipment, and the usual direct and indirect costs associated with installing or erecting new control equipment. These costs, in **second-quarter 1987** dollars, are described in the following subsections.*

6.3.1 Equipment Cost

6.3.1.1 ESP Costs

Five types of ESPs are considered: plate-wire, flat plate, wet, tubular, and two-stage. Basic

*For information on escalating these prices to more current dollars, refer to the EPA report *Escalation Indexes for Air Pollution Control Costs* and updates thereto, all of which are installed on the OAQPS Technology Transfer Network (CTC Bulletin Board).

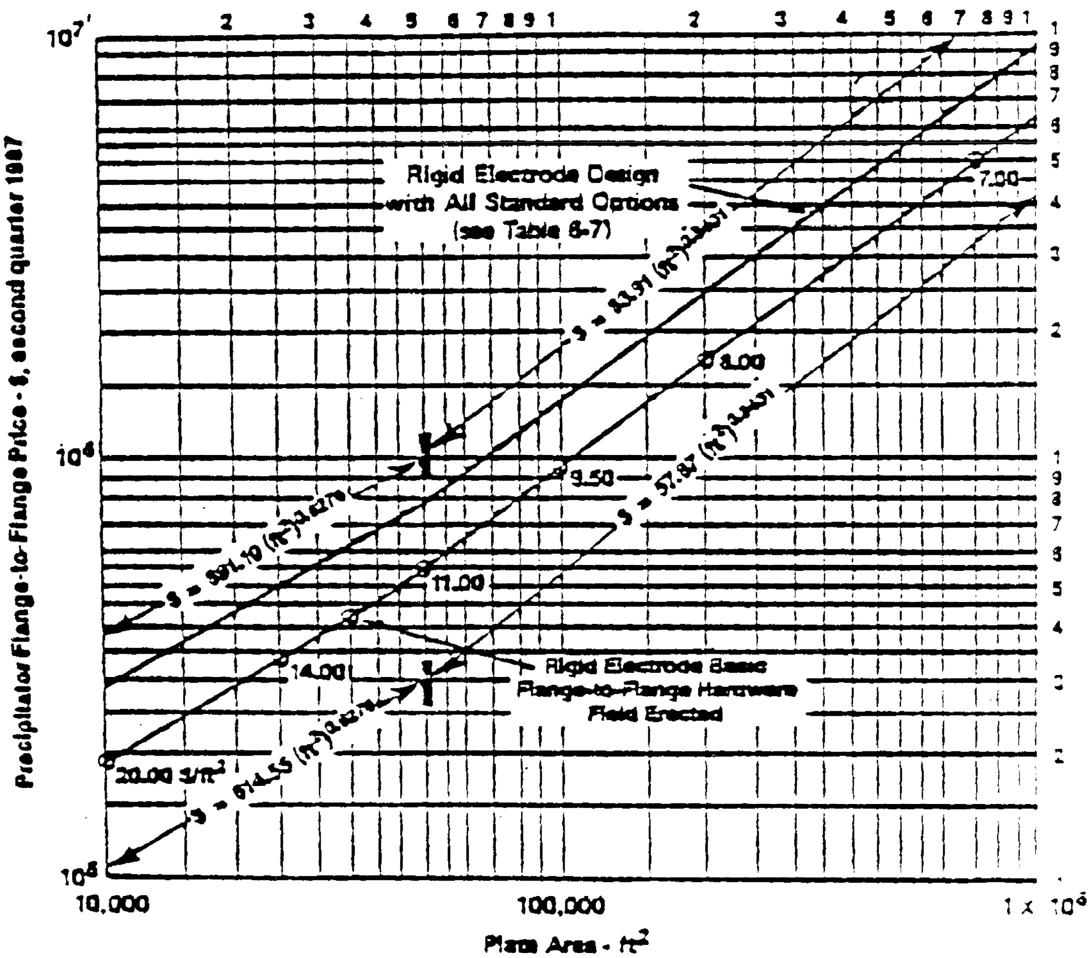

Figure 6.5: Dry-type ESP flange-to-flange purchase price vs. plate area.

costs for the first two are taken from Figure 6.5, which gives the flange-to-flange, field-erected price based on required plate area and a rigid electrode design. This plate area is calculated from the sizing information given previously for the four types. Adjustments are made for standard options listed in Table 6.7. Costs for wet/tubular ESPs are discussed under Recent Trends, below, and costs for two-stage precipitators are given in a later subsection.

The costs are based on a number of actual quotes. Least squares lines have been fitted to the quotes, one for sizes between 50,000 and 1,000,000 ft^2 and a second for sizes between 10,000 and 50,000 ft^2. An equation is given for each line. Extrapolation below 10,000 or above 1,000,000 ft^2 should not be used. The reader should not be surprised if quotes are obtained that differ from these curves by as much as ±25 percent. Significant savings can be had by soliciting multiple quotes. All Units include the ESP casing, pyramidal hoppers, rigid electrodes and internal collecting plates, transformer rectifier (TR) sets and microprocessor controls, rappers, and stub supports (legs) for 4 feet clearance below the hopper discharges. The lower curve is the basic unit without the standard options. The upper curve includes all of the standard options (see Table 6.7) that are normally utilized in a modern system. These options add approximately 45 percent to the basic cost of the flange-to-flange hardware. Insulation costs are for 3 in. of field-installed glass fiber encased in a metal skin and applied on the outside of all areas in contact with the exhaust gas stream. Insulation for ductwork, fan casings, and stacks must be calculated separately.

Impact of alternative electrode designs All three designs—rigid electrode, weighted wire, and rigid frame—can be employed in most applications. Any cost differential between designs will depend on the combination of vendor experience and site-specific factors that dictate equipment size factors. The rigid frame design will cost up to 25 percent more if the mast or plate height is restricted to the same used in other designs. Several vendors can now provide rigid frame collectors with longer plates, and thus the cost differential can approach zero.

The weighted wire design uses narrower plate spacings and more internal discharge electrodes. This design is being employed less; therefore, its cost is increasing and currently is approximately the same as that for the rigid electrode collector. Below about 15,000 ft^2 of plate area, ESPs are of different design and are not normally field erected, and the costs will be significantly different from values extrapolated from Figure 6.5.

Impact of materials of construction Metal thickness and stainless steel Corrosive or other adverse operating conditions may suggest the specification of thicker metal sections in the precipitator. Reasonable increases in metal sections result in minimal cost increases. For example, collecting plates are typically constructed of 18 gauge mild steel. Most ESP manufacturers can increase the section thickness by 25 percent without significant design changes or increases in manufacturing costs of more than a few percent.

Changes in type of material can increase purchase cost of the ESP from about 30 to 50 percent for type 304 stainless steel collector plates and precipitator walls, and up to several hundred percent for more expensive materials used for all elements of the ESP. Based on the type 304 stainless steel cost, the approximate factors given below can be used for other materials:

Material	Factor	Reference(s)
Stainless steel, 316	1.3	[4,5,6]
Carpenter 20 CB-3	1.9	[6]
Monel-400	2.3	[4,6]
Nickel-200	3.2	[6]
Titanium	4.5	[6]

Appendix 6A provides more detail on the effects of material thickness and type.

Recent trends most of today's market (1987) is in the 50,000 to 200,000 ft^2 plate area size range. ESP selling prices have increased very little over the past 10 years because of more effective designs, increased competition from European suppliers, and a shrinking utility market.

Design improvements have allowed wider plate spacings that reduce the number of internal components and higher plates and masts that provide additional plate area at a low cost. Microprocessor controls and energy management systems have lowered operating costs.

Few, if any, hot-side ESPs (those used upstream from an air preheater on a combustion source) are being specified for purchase. Recognition that low sodium coals tend to build resistive ash layers on the collection plates, thus reducing ESP efficiency, has almost eliminated sales of these units. Of about 150 existing units, about 75 are candidates for conversion to cold-side units over the next 10 years.

Specific industry application has little impact on either ESP design or cost, with three exceptions: paper mills and sulfuric acid manufacturing plants, and coke by-product plants. Paper mill ESPs use drag conveyor hoppers that add approximately 10 percent to the base flange-to-flange equipment cost. For emissions control in sulfuric acid plants and coke byproduct ovens, wet ESPs are used. In sulfuric acid manufacture, wet ESPs are used to collect acid mist. These precipitators usually are small, and they use lead for all interior surfaces; hence, they normally cost \$65 to \$95/ft^2 of collecting area installed (mid-1987 dollars) and up to \$120/ft^2 in special situations. In addition, a wet circular ESP is used to control emissions from a coke oven off-gas detarring operation. These precipitators are made using high-alloy stainless steels and typically cost \$90 to \$120/ft^2, installed. Because of the small number of sales, small size of units sold, and dependency on site-specific factors, more definitive costs are not available.

6.3.1.2 Retrofit Cost Factor

Retrofit installations increase the costs of an ESP because of the common need to remove something to make way for the new ESP. Also, the ducting usually is much more expensive. The ducting path is often constrained by existing structures, additional supports are required, and the confined areas make erection more labor intensive and lengthy. Costs are site-specific; however, for estimating purposes, a retrofit multiplier of 1.3 to 1.5 applied to the total capital investment can be used. The multiplier should be selected within this range based on the relative difficulty of the installation.

A special case is conversion of hot-to-cold side ESPs for coal-fired boiler applications. The magnitude of the conversion is very site-specific, but most projects will contain the following elements:

- Relocating the air preheater and the ducting to it
- Resizing the ESP inlet and outlet duct to the new air volume and rerouting it
- Upgrading the ID (induced draft) fan size or motor to accommodate the higher static pressure and horsepower requirements
- Adding or modifying foundations for fan and duct supports
- Assessing the required SCA and either increasing the collecting area or installing an SO_3 gas-conditioning system
- Adding hopper heaters
- Upgrading the analog electrical controls to microprocessor-type controls
- Increasing the number of collecting plate rappers and perhaps the location of rapping

In some installations, it may be cost-effective to gut the existing collector totally, utilize only the existing casing and hoppers, and upgrade to modern internals.

The cost of conversion is a multimillion dollar project typically running at least 25 to 35 percent of the total capital investment of a new unit.

6.3.1.3 Auxiliary Equipment

The auxiliary equipment depicted in Figure 6.2 is discussed elsewhere in the *Manual*. Because dust-removal equipment (*e.g.*, screw conveyers), hoods, precoolers, cyclones, fans, motors, and stacks are common to many pollution control systems, they are (or will be) given extended treatment in separate chapters.

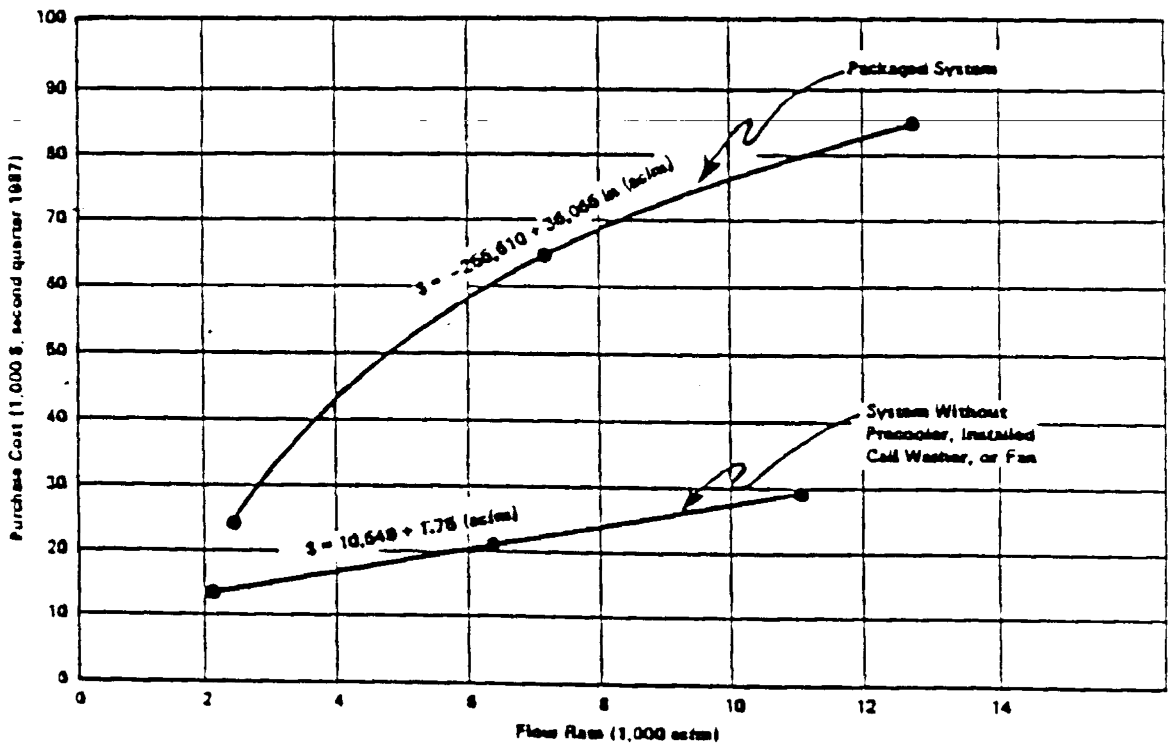

Figure 6.6: Purchase Costs for Two-stage, Two-cell Precipitators (7)

6.3.1.4 Costs for Two-Stage Precipitators

Purchase costs for two-stage precipitators, which should be considered separately from large-scale, single-stage ESPs, are given in Figure 6.6.[7] To be consistent with industry practice, costsare given as a function of flow rate through the system. The lower cost curve is for a two-cell unit without precooler, an installed cell washer, or a fan. The upper curve is for an engineered, package system with the following components: inlet diffuser plenum, prefilter, cooling coils with coating, coil plenums with access, water flow controls, triple pass configuration, system exhaust fan with accessories, outlet plenum, and in-place foam cleaning system with semiautomatic controls and programmable controller. All equipment is fully assembled mechanically and electrically, and it is mounted on a steel structural skid.

Table 6.8: Items That Increase ESP Costs

Item	Factor	Applied to
Rigid frame electrode with restricted plate height	1.0 to 1.25	ESP Base cost
Type 304 stainless steel collector plates and precipitator walls*	1.3 to 1.5	"
All stainless steel construction*	2 to 3	"
ESP with drag conveyor hoppers (paper mill)	1.1	"
Retrofit installations	1.3 to 1.5	ESP total capital investment (new facility installation)
Wet ESP		
Sulfuric acid mist	See 6.3.1.1.	—
Sulfuric acid mist (special installation)	See 6.3.1.1.	—
Coke oven off gas	See 6.3.1.1.	—

*See table on page 6-42 for other materials' cost factors.

6.3.2 Total Purchased Cost

The total purchased cost of an ESP system is the sum of the costs of the ESP, options, auxiliary equipment, instruments and controls, taxes, and freight. The last three items generally are taken as percentages of the estimated total cost of the first three items. Typical values, from Chapter 2 of the *Manual*, are 10 percent for instruments and controls, 3 percent for taxes, and 5 percent for freight.

Costs of standard and other options can vary from 0 to more than 150 percent of bare ESP cost, depending on site and application requirements. Other factors that can increase ESP costs are given in Table 6.8.

6.3.3 Total Capital Investment (TCI)

Using the Chapter 2 methodology, TCI is estimated from a series of factors applied to the purchased equipment cost to obtain direct and indirect costs for installation. The TCI is the sum of these three costs. The required factors are given in Table 6.9. Because ESPs may vary from small units attached to existing buildings to large, separate structures, specific factors for site preparation or for buildings are not given. However, costs for buildings may be obtained from such references as *Means Square Foot Costs 1987* [10]. Land, working capital, and off-site facilities are excluded from the table because they are not normally required. For very large installations, however, they may be needed and could be estimated on an as-needed basis.

Note that the factors given in Table 6.9 are for average installation conditions, *e.g.*, no unusual problems with site earthwork, access, shipping, or interfering structures. Considerable variation may be seen with other-than-average installation circumstances. For two-stage precipitators purchased as packaged systems, several of the costs in Table 6.9 would be greatly reduced or eliminated. These include instruments and controls, foundations and supports, erection and handling, painting, and model studies. An installation factor of 0.20 B to 0.25 B would be more nearly appropriate for the two-stage ESPs.

6.4 Estimating Total Annual Costs

6.4.1 Direct Annual Costs

Direct annual costs include operating and supervisory labor, operating materials, replacement rappers and electrodes, maintenance (labor and materials), utilities, dust disposal, and wastewater treatment for wet ESPs. Most of these costs are discussed individually below. They vary considerably with location and time and, for this reason, should be obtained to suit the specific ESP system being costed. For example, current labor rates may be found in such publications as the *Monthly Labor Review*, published by the U.S. Department of Labor, Bureau of Labor Statistics.

6.4.1.1 Operating and Supervisory Labor

Proper operation of the ESP is necessary both to meet applicable particulate emission regulations and to ensure minimum costs. An ESP is an expensive piece of equipment. Even well-designed equipment will deteriorate rapidly if improperly maintained and will have to be replaced long before it should be necessary. Not only can proper operation and maintenance save the operator money, such an operation and maintenance program can also contribute to good relations with the governing pollution control agency by showing good faith in efforts to comply with air regulations.

Although each plant has its own methods for conducting an operation and maintenance program, experience has shown that plants that assign one individual the responsibility of coordinating all the pieces of the program operate better than those where different departments look after only a certain portion of the program. The separate departments have little knowledge of how their portion impacts the overall program. In other words, a plant needs one individual to coordinate the operation, maintenance, and troubleshooting components of its ESP program if it expects to have a relatively trouble-free operation. The coordinator typically is an engineer who reports to plant management and interfaces with the maintenance and plant process supervisors, the laboratory, and the purchasing department. For companies with more than one plant, he would be responsible for all ESPs. The portion of his total time that this individual spends an the ESP then becomes an operating expense for the ESP. This can be expressed as:

$$AC = X(LCC) \tag{6.25}$$

where

AC	=	annual coordination cost (\$/yr)
X	=	fraction of total time spent on ESP
LCC	=	individual annual labor cost for ESP coordinator (\$/yr)

In addition to coordination costs, typical operating labor requirements are 1/2 to 2 hours per shift for a wide range of ESP sizes.[8] Small or well-performing units may require less time, and very large or troublesome units may require more time. Supervisory labor is taken as 15 percent of operating labor.

6.4.1.2 Operating Materials

Operating materials are generally not required for ESPs. An exception is the use of gas-preconditioning agents for dust resistivity control.

Table 6.9 Capital Cost Factors for ESPs[a]

Cost Item	Factor
Direct Cost	
Purchase equipment costs	
ESP + auxiliary equipment	As estimated, A
Instrumentation	0.10 A
Sales taxes	0.03 A
Freight	0.05 A
Purchased equipment cost, PEC	B = 1.18 A
Direct installation costs	
Foundations & supports	0.04 B
Handling & erection	0.50 B
Electrical	0.08 B
Piping	0.01 B
Insulation for ductwork[b]	0.02 B
Painting	0.02 B
Direct installation costs	0.67 B
Site preparation	As required, SP
Buildings	As required, Bldg.
Total Direct Cost, DC	1.67 B + SP - Bldg.
Indirect costs (installation)	
Engineering	0.20 B
Construction and field expenses	0.20 B
Contractor fees	0.10 B
Start-up	0.01 B
Performance test	0.01 B
Model study	0.02 B
Contingencies	0.03 B
Total Indirect Costs, IC	0.57 B
Total Capital Investment = DC + IC	2.24 B + SP + Bldg.

[a]Reference (8)

[b]If ductwork dimensions have been established, cost may be estimated based on \$10 to \$12/ft^2 (fourth quarter 1986) of surface for field application. (Alternatively, refer to Chapter 10 of this manual.) Fan housings and stacks may also be insulated. (9)

[c]For two-stage precipitators, total installation direct costs are more nearly 0.20 to 0.25B + SP + Bldg.

6.4.1.3 Maintenance

The reader should obtain Publication No. EPA/625/1-85/017, *Operating and Maintenance Manual for ESPs,*[11] for suggested maintenance practices. Routine ESP maintenance labor costs can be estimated using data provided by manufacturers. If such data are unavailable, the following procedure can be used. Based on data for a 100,000 ft^2 collector, maintenance labor is estimated to require 15 h/wk, 44 wk/yr. At a direct labor cost of $12.50/h (mid-1987 costs), an estimated annual maintenance labor cost of $8,250 or $0.0825/$ft^2$ of collector area is established. This relationship can be assumed to be linear above a 50,000 ft^2 collector-size and constant at $4,125 below this size. To the maintenance labor cost must be added the cost of maintenance materials. Based on an analysis of vendor information, annual maintenance materials are estimated as 1 percent of the flange-to-flange precipitator purchase cost:

$$MC = 0.01(FCC) \quad \text{labor cost} \tag{6.26}$$

where

MC	=	annual maintenance cost ($/yr)
FCC	=	ESP flange-to-flange purchase cost ($)
labor cost	=	$4,125 if A < 50,000 ft^2
		0.825 A if > 50,000ft^2
where A = ESP		plate area (ft^2)

6.4.1.4 Electricity

Power is required to operate system fans, transformer-rectifier (TR) sets, and cleaning equipment. Fan power for primary gas movement can be calculated from Equation 2.7 of the *Manual*. After substituting into this equation a combined fan-motor efficiency of 0.65 and a specific gravity of 1.0, we obtain:

$$FP = 0.000181Q(\Delta P)(\theta) \tag{6.27}$$

where

FP	=	fan power requirement (kWh/yr)
Q	=	system flow rate (acfm)
ΔP	=	system pressure drop (in. H_2O)
θ'	=	annual operating time (h/yr)

Pump power for wet ESPs can be calculated from [8]:

$$PP = (0.746 Q_l Z S_g \theta)/(3{,}960\eta) \tag{6.28}$$

where

PP	=	pump power requirement (kWh/yr)
Q	=	water flow rate (gal/min)
Z	=	fluid head (ft)
S_g	=	specific gravity of water being pumped compared to water at 70°F and 29.92 in. Hg
θ'	=	annual operating time (h/yr)
η	=	pump-motor efficiency (fractional)

Energy for TR sets and motor-driven or electromagnetic rapper systems is the sum of the energy consumption for operating both items. Manufacturers' averaged data indicate that the following relationship can be used:

$$OP = 1.94 \times 10^{-3} A \grave{e}^{1} \tag{6.29}$$

where

OP	=	annual ESP operating power (kWh/yr)
A	=	ESP plate area (ft^2)
θ'	=	annual operating time (h/yr)

For installations requiring hopper heaters, hopper heater power can be similarly estimated:

$$HH = 2(HN)\grave{e} \tag{6.30}$$

where

HH	=	annual hopper heater power consumption (kWh/yr)
HN	=	number of hoppers
θ'	=	annual operating time (h/yr)

For two-stage precipitators, power consumption ranges from 25 to 100 W/kacfm, with 40 W/kacfm being typical.

6.4.1.5 Fuel

If the ESP or associated ductwork is heated to prevent condensation, fuel costs should be calculated as required. These costs can be significant, but they may be difficult to predict. For methods of calculating heat transfer requirements, see Perry [12].

6.4.1.6 Water

Cooling process gases for preconditioning can be done by dilution with air, evaporation with water, or heat exchange with normal equipment. Spray cooling requires consumption of plant water (heat exchangers may also require water), although costs are not usually significant. Section 4.4 of the *Manual* provides information on estimating cooling water costs. Water consumption in wet ESPs is estimated at 5 gal/min kacfm [13] for large single-stage units and 16 gal/min-kacfm for two-stage precipitators [14].

6.4.1.7 Compressed Air

ESPs may use compressed air at pressures of about 60 to 100 psig for operating rappers. Equivalent power cost is included in Equation 6.29 for operating power.

6.4.1.8 Dust Disposal

If collected dust cannot be recycled or sold, it must be landfilled or disposed of in some other manner. Costs may typically run $20/ton or $30/ton for nonhazardous wastes exclusive of transportation (see Section 2.4 of the *Manual*). Landfilling of hazardous wastes may cost 10 times as much. The disposal costs are highly site-specific and depend on transportation distance to the landfill, handling rates, and disposal unloading (tipping) fees. If these factors are known, they lead to the relationship:

$$DD = 4.29 \times 10^{-6} G \theta' \; Q[T \quad (TM)D] \tag{7.6}$$

where

DD = annual dust disposal cost ($/yr)
G = ESP inlet grain loading or dust concentration (gr /ft^3)
θ' = annual operating time (h/yr)
Q = gas flow rate through ESP (acfm)
T = tipping fee ($/ton)
TM = mileage rate ($/ton-mile)
D = dust hauling distance (miles)

6.4.1.9 Wastewater Treatment

As indicated above, the water usage for wet ESPs is about 5 gal/min kacfm [13]. Treatment cost of the resulting wastewater may vary from about \$1.30 to \$2.15/1,000 gal [15] depending on the complexity of the treatment system. More precise costs can be obtained from Gumerman *et al.* [16].

6.4.1.10 Conditioning Costs

Adaptation of information on utility boilers [17] suggests that $S0_3$ conditioning for a large ESP (2.6 x 10^6 acfm) costs from about \$1.60/10^6 ft^3 of gas processed for a sulfur burner providing 5 ppm SO_3 to about \$2.30/10^6 ft^3 (in first-quarter 1987 dollars) for a liquid SO_2 system providing 20 ppm of $S0_3$.

6.4.2 Indirect Annual Costs

Capital recovery, property taxes, insurance, administrative costs ("G&A"), and overhead are examples of indirect annual costs. The capital recovery cost is based on the equipment lifetime and the annual interest rate employed. (See Chapter 2 for a thorough discussion of the capital recovery cost and the variables that determine it.) For ESPs, the system lifetime varies from 5 to 40 years, with 20 years being typical. Therefore, as Chapter 2 of the *Manual* suggests, when figuring the system capital recovery cost, one should base it on the total capital investment. In other words:

$$CRC_s = TCI \times CRF_s \tag{6.32}$$

where

CRC_s = capital recovery cost for ESP system (\$/yr)
TCI = total capital investment (\$)
CRF_s = capital recovery factor for ESP system (defined in Chapter 2)

For example, for a 20-year system life and a 7 percent annual interest rate, the CRFs would be 0.09439.

The suggested factor to use for property taxes, insurance, and administrative charges is 4 percent of the TCI. Overhead is calculated as 60 percent of the sum of operating, supervisory, coordination, and maintenance labor, as well as maintenance materials.

6.4.3 Recovery Credits

For processes that can reuse the dust collected in the ESP or that can sell the dust in a local market, such as fly ash sold as an extender for paving mixes, a credit should be taken. As used below, this credit (RC) appears as a negative cost.

6.4.4 Total Annual Cost

Total annual cost for owning and operating an ESP system is the sum of the components listed in Subsections 6.4.1 through 6.4.3, *i.e.*:

$$TAC = DC \quad IC - RC \tag{6.33}$$

where

TAC	=	total annual cost ($)
DC	=	direct annual cost ($)
IC	=	indirect annual cost ($)
RC	=	recovery credits (annual) ($)

6.4.5 Example Problem

Assume an ESP is required for controlling fly ash emissions from a coal-fired boiler burning bituminous coal. The flue gas stream is 50 kacfm at 325°F and has an inlet ash loading of 4 gr/ft^3. Analysis of the ash shows of 7 µm and a resistivity of less than 2 x 10^{11} ohm-cm. Assume that the ESP operates for 8,640 h/yr (360 d) and that an efficiency of 99.9 percent is required.

6.4.5.1 Design SCA

The SCA can be calculated from Equation 6.23. Assuming that a flat plate
ESP design is chosen, the fly ash migration velocity is 16.0 cm/ s (see Table 6.4). Then:

$$\text{SCA} = -\ln(1 - 0.999)/16.0 = 0.432 \text{ s/cm} = 43.2 \text{ s/m}$$

Converting to English units (see page 6-33, Step 15, in the procedure):

$$\text{ESCA} = 5.080 \times 43.2 = 219 \text{ ft}^2/\text{kacfm}$$

Total collector plate area is then:

$$219 \text{ ft}^2/\text{kacfm} \times 50 \text{ kacfm} = 10.950 \text{ ft}^2$$

To obtain a more rigorous answer, we can follow the steps of the procedure given in Subsection 6.2.1:

Step 1 – Design efficiency is required as 99.9.

Step 2 – Design penetration:

$$1 - (99.9/100) = 0.001$$

Step 3 – Operating temperature in Kelvin:

$$(325°F - 32°F) \times 5/9 \quad 273°C = 436°K$$

Step 4 – Because dust resistivity is less than 2×10^{11} ohm-cm (see page 6-30, Step 4), no severe back corona is expected and back corona = 0.

Step 5 – The MMD of the fly ash is given as 7 µm.

Step 6 – Values for sneakage and rapping reentrainment (from the table presented in Step 6, page 6-24) are:

SN = 0.10
RR = 0.124 (assuming gas velocity <1-5 m/s)

Step 7 – The most penetrating particle size, from Step 7 of the procedure on page 6-31, is:

$$\text{MMD}_p = 2\mu m$$

The rapping puff size is:

$$\text{MMD}_r = 5\mu m$$

Step 8 – From the procedure (Subsection 6.2.1):

ϵ_o = 8.845×10^{-12}
η = $1.72 \times 10^{-5}(436/273)^{0.71} = 2.40 \times 10^{-5}$
E_{bd} = $6.3 \times 10^{5}(273/436)^{1.65} = 2.91 \times 10^{5}$ V/m
E_{avg} = $E_{bd} \times 5/6.3 = 2.31 \times 10^{5}$
LF = $S_N + RR(l - S_N) = 0.1 + 0.124(1 - 0.1) = 0.212$

Step 9 – Choose the number of sections for $LF^n < p$, $p = 0.001$. Try four sections:

$$LF^n = 0.212^4 = 0.002$$

This value is larger than p. Try five sections:

$$LF^n = 0.212^5 = 0.000428$$

This value is smaller than p and is acceptable.

Step 10 – Average section penetration is:

$$p_s = p^{1/n} = 0.001^{1/5} = 0.251$$

Step 11 – Section collection penetration is:

$$p_c = (p_s - LF)/(1 - LF) = (0.251 - 0.212)/(1 - 0.212) = 0.0495$$

Step 12 – Particle size change factors are:

$$\begin{aligned}
D &= p_s = S_N \quad p_c(1 - S_N) \quad RR(1 - S_N)(1 - p_c) \\
&= 0.10 \quad 0.0495(1 - 0.) \quad 0.214(1 - 0.1)(1 - 0.0495) \\
&= 0.251 \\
\mathrm{MMD}_{\mathrm{rp}} &= RR(1 - S_N)(1 - p_c)MMD_r/D \\
&= 0.124(1 - 0.1)(1 - 0.0495)(5)/0{,}251 \\
&= 2.11
\end{aligned}$$

Step 13 - Particle sizes for each section are:

Section			MMD (μm)
1	MMD_1	=	$MMD_i = 7$
2	MMD_2	=	$\{MMD_1 \times S_N + [(1 - p_c) \times MMD_p + p_c \times MMD_1] \times p_c\}/D + MMD_{rp}$
		=	$\{7 \times 0.1 + [(1 - 0.0495) \times 2 + 0.0495 \times 7] \times 0.0495\}/0.251 + 2.11$
		=	5.34
3	MMD_3	=	$\{5.34 \times 0.1 + [(1 - 0.0495) \times 2 + 0.0495 \times 5.34] \times 0.0495\}/0.251 + 2.11$
		=	4.67
4	MMD_4	=	$\{4.67 \times 0.1 + [(1 - 0.0495) \times 2 + 0.0495 \times 4.67] \times 0.0495\}/0.251 + 2.11$
		=	4.39
5	MMD_5	=	$\{4.39 \times 0.1 + [(1 - 0.0495) \times 2 + 0.0495 \times 4.39] \times 0.0495\}/0.251 + 2.11$
		=	4.28

Step 14 – SCAs for each section are:

Section			SCA (s/m)
1	SCA_1	=	$-(\eta/\epsilon 0) \times (1 - S_N) \times \ln(p_c)/(E_{avg}^2 \times MMD_1 \times 10^{-6})$
		=	$-(2.40 \times 10^{-5}/8.845 \times 10^{-12})(1 - 0.1) \times \ln(0.0495)/[(2.31 \times 10^5)^2(7 \times 10^{-6})]$
		=	19.65
2	SCA_2	=	$SCA_1 \times MMD_1/MMD_2$
		=	19.65 (7/5.34)
		=	25.76
3	SCA_3	=	25.76 (5.34/4.67)
		=	29.46
4	SCA_4	=	29.46 (4.67/4.39)
		=	31.34
5	SCA_5	=	31.34 (4.39/4.28)
		=	32.15

Step 15 – Calculate the total SCA.

Total SCA = 19.65 + 25.76 + 29.46 + 31.34 + 32.15 = 138.36 s/m

English SCA = 5.080 x 138.36 = 702.87 ft^2/kacfm

Note that the more rigorous procedure calls for an SCA that is considerably higher than the value found by using Equation 6.23. This discrepancy is caused by the considerably smaller particle size used in the example problem than is assumed for Table 6.4. In this case, the shorter method would lead to an unacceptably low cost estimate.

Total collector plate area is:

$$702.87\ ft^2/kacfm \times 50\ kacfm = 35{,}144\ ft^2$$

6.4.5.2 ESP Cost

From Figure 6.5, the basic flange-to-flange cost of the rigid electrode ESP is $438,060 (mid-1987 dollars). Assuming all standard options are purchased. the ESP cost rises to $635,189 (mid-1987 dollars).

6.4.5.3 Costs of Auxiliaries

Assume the following auxiliary costs have been estimated from data in other parts of the *Manual*:

Ductwork	$16,000
Fan	16,000
Motor	7,500
Starter	4,000
Dampers	7,200
Pneumatic conveyor	4,000
Stack	8,000
Total	$62,700

6.4.5.4 Total Capital Investment Direct costs for the ESP system, based on the factors in Table 6.9, are given in Table 6.10. (Again, we assume site preparation and building costs to be negligible.) TCI is $1,840,000 (rounded, mid-1987 dollars).

6.4.5.5 Annual Costs-Pressure Drop

Table 6.11 gives the direct and indirect annual costs, as calculated from the factors given in Section 6.4. Pressure drop (for energy costs) can be taken from Table 6.6 in Subsection 6.2.2. Using the higher values from the table, pressure drop for the inlet diffuser plate, inlet and outlet transitions, baffles, and plates is:

$$\Delta P = 0.09 + 0.14 + 0.015 + 0.123 + 0.008 = 0.38 \text{ in. } H_2O$$

Assume the ductwork contributes an additional 4.1 in. H_2O.* The total pressure drop is, therefore, 4.48 in. H_2O. As is typical, the ductwork pressure drop overwhelms the ESP pressure drop.

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*For ductwork pressure drop data, refer to Chapter 10 ("Hoods, Ductwork, and Stacks") of the *Manual*.

Table 6.10: Capital Costs for ESP System
Example Problem

Cost Item	Cost
Direct Costs	
Purchased equipment costs	
Adsorber vessels and carbon	$635,189
Auxiliary equipment	62,700
Sum = A	$697,889
Instrumentation, 0.1A	69,789
Sales taxes, 0.03A	20,937
Freight, 0.05A	34,894
Purchased equipment cost, B	$823,509
Direct installation costs	
Foundation and supports, 0.04B	32,940
Handling & erection, 0.50B	411,755
Electrical, 0.08B	65,881
Piping, 0.01B	8,235
Insulation for ductwork, 0.02B	16,470
Painting, 0.02B	16,470
Direct installation cost	$551,751
Site preparation	—
Facilities and buildings	—
Total Direct Cost	$1,375,260
Indirect Costs (installation)	
Engineering, 0.20B	164,702
Construction and field expenses, 0.20B	164,702
Contractor fees, 0.10B	82,351
Start-up, 0.01B	8,235
Performance test, 0.01B	8,235
Model study, 0.02B	16,470
Contingencies, 0.03B	24,705
Total Indirect Cost	$469,400
Total Capital Investment (rounded)	$1,840,000

Table 6.11: Annual Costs for ESP System
Example Problem

Cost Item	Calculations	Cost
Direct Annual Costs, DC		
Operating labor		
Operator	$\frac{3\ h}{day} \times \frac{360\ days}{yr} \times \frac{\$12}{h}$	$12,960
Supervisor	15% of operator = .15 × 12,960	1,944
Coordinator	1/3 of operator = 1/3 × 12,960	4,320
Operating materials		—
Maintenance		
Labor	$ 4,125 for collector area < 50,000 ft^2	4,125
Material	1% of Purchased equipment cost = 0.01 × 823,509	8,235
Utilities		
Electricity–fan	$0.000181 \times 50,000$ acfm $\times 4.48$ in. H_2O $\times \frac{8,640\ h}{yr} \times \frac{\$0.06}{kWh}$	21,018
Electricity–operating	$1.94 \times 10^{-3} \times 35,144\ ft^2 \times 8,640\ h \times \$0.06/kWh$	35,344
Waste disposal	at $20/ton tipping fee at 2 miles and $0.50/ton-mile for essentially 100% collection efficiency: $4.29 \times 10^{-6} \times \frac{4\ gr}{ft^3} \times \frac{8,640\ h}{yr} \times 50,000$ acfm $\times (20 + 0.50 \times 2) \frac{\$}{ton}$	155,676
Total DC		$243,622
Indirect Annual Costs, IC		
Overhead	60% of sum of operating, supv., coord., & maint. labor & maint. materials = 0.6(12,960 + 1,944 + 4,320 + 4,125 + 8,235)	18,950
Administrative charges	2% of Total Capital Investment = 0.02($1,844,660)	36,893
Property tax	1% of Total Capital Investment = 0.01($1,844,660)	18,447
Insurance	1% of Total Capital Investment = 0.01($1,844,660)	18,447
Capital recovery[a]	0.1175 (1,844,660)	216,748
Total IC		$309,485
Total Annual Cost (rounded)		$553,000

[a] The capital recovery cost factor, CRF, is a function of the fabric filter or equipment life and the opportunity cost of the capital (*i.e.*, interest rate). For example, for a 20 year equipment life and a 10% interest rate, CRF = 0.1175.

6.4.5.8 Total Annual Cost The total annual cost, calculated in Table 6.11, is $511,000 (rounded). Had the particle sizes being captured been larger, the ESP cost would have been considerably less. Also, for a much larger gas flow rate, the $/acfm treated cost would have been more favorable. Reviewing components of the TAC, dust disposal is the largest single item. Care should be taken in determining this cost and the unit disposal cost ($/ton). Finding a market for the dust, for example, as an extender in asphalt or a dressing for fields, even at giveaway prices, would reduce TAC dramatically.

6.5 Acknowledgments

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Appendix 6A

Effects of Material Thickness and Type on ESP Costs

The impact of material thickness and composition of collecting plates and the ESP casing can be estimated using the following equations and Figure 6.5:

Plates:

$$I = \frac{\left| \frac{W_t}{2} \times FS) - 0.90 \right| M \quad SP}{SP} \tag{6.34}$$

Casing:

$$I = \frac{\left| \frac{W_t}{10} \times FS) - 0.58 \right| M \quad SP}{SP} \tag{6.35}$$

where

I	=	incremental increase of flange-to-flange selling price ($\$/ft^2$)
W_t	=	weight of steel (lb/ft^2)
FS	=	fabricated steel selling price (\$/lb) (normally assume approximately 2 times material cost)
M	=	manufacturer's markup factor of fabricated cost (direct labor, wages, and material cost before general and administrative expense and profit) to selling price (normally 2 to 3)
SP	=	flange-to-flange selling price from Figure 6.5 ($\$/ft^2$)

Most vendors can produce ESPs with collecting plate material thicknesses from 16 to 20 gauge and casing material thicknesses from 1/8 through 1/4 in. without affecting the 2 times material cost = fabricated cost relationship. Thus, the impact of increasing the collecting plates from 18 to 16 gauge and the casing from 3/16 to 1/4 in. plate on a 72,000 ft^2 collector having a selling price of $\$10/ft^2$ and assuming a markup factor of 2 is as follows:

Plates:

$$I = \frac{\left[\left(\frac{2.5}{2} \times 0.90\right) - 0.90\right] 2 \quad 10}{10}$$

$$= 1.045 = 4.5 \text{ percent increase}$$

Casing:

$$I = \frac{\left[\left(\frac{10.21}{10} \times 0.76\right) - 0.58\right] 2 \quad 10}{10}$$

$$= 1.039 = 3.9 \text{ percent increase}$$

Equations 6.34 and 6.35 were developed using the following assumptions:

$$\text{I} = \frac{\text{Material selling price increase} \quad \text{Standard ESP selling price}}{\text{Standard ESP selling price}}$$

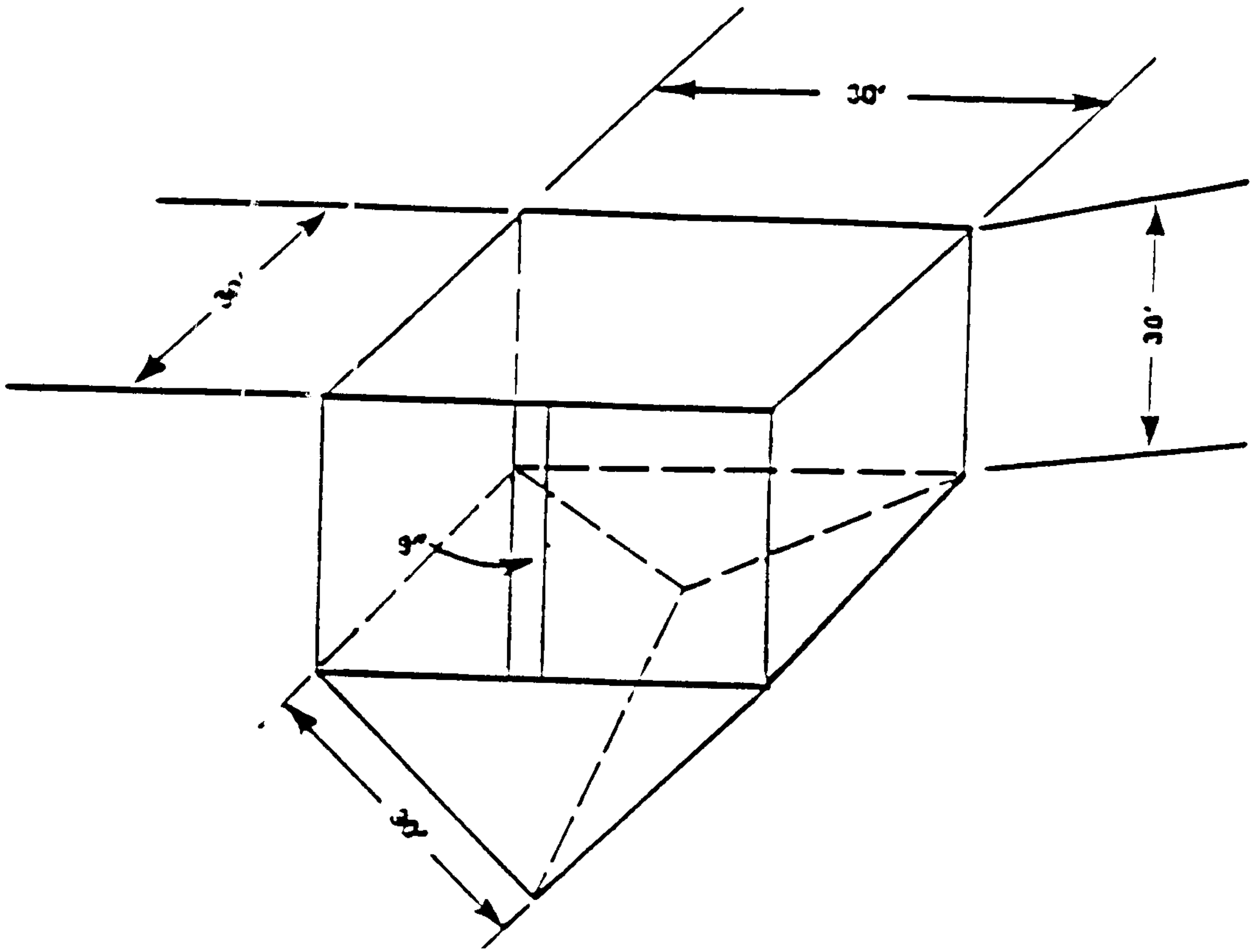

Figure 6.7: ESP Dimensions

Because figure 6.5 identifies the standard ESP selling price /ft^2 of collecting area, the material selling price increase = (New material cost - Standard material cost)M. Then it follows that:

$$\text{Material selling price} = \frac{\text{lb steel}}{\text{ft}^2 \text{ collecting area}} \times \text{Fabricated cost in \$/lb} \times M$$

The ESP dimensions given in Figure 6.7 include:

- Casing area = 30 ft 30 ft x 8 = 7,200 ft^2 (assume 4 walls, 1 top, 2 hopper sides, 2 triangular hopper ends ≈ 8 equivalent sides)

- Collecting plate area =

$$30 \text{ ft} \times 30 \text{ ft} \times 2 \text{ sides/plate} \times \frac{30 \text{ ft}}{s} \text{ plates}$$
$$= \frac{54{,}000}{s} \text{ft}^2 = 72{,}000 \text{ ft}^2 \text{ for } s = 0.75\text{ft}$$

where s = plate spacing (ft)

Thus, there are:

- 7.50/s ft^2 of collecting area per 1 ft^2 of casing and

- 2 ft^2 of collecting area per 1 ft^2 of collecting plate

Material cost per ft^2 collecting area is:

$$\text{Plates} = \frac{\text{lb steel/ft}^2}{2} \times \$/\text{lb}$$
$$\text{Casing} = \frac{\text{lb steel/ft}^2}{7.50/s} \times \$/\text{lb}$$

For the standard ESPs described by Figure 6.5, 18 gauge collecting plates and 3/16 in. plate casing were specified. Assuming:

Material cost for 18 gauge mild steel	=	$0.45/lb
Material cost for 3/16 in. plate mild steel	=	$0.38/lb
Material cost to fabricated cost factor	=	2

These costs yield fabricated material costs of:

<u>Plates:</u>

$$\frac{2 \text{ lb/ft}^2}{2} \times \$0.45/\text{lb} \times 2 = \$0.90/\text{ft}^2 \text{ of collecting area}$$

Casing:

$$\frac{7.66\ \text{lb/ft}^2}{7.50/s} \times \$0.38 \times 2 = \$0.78\ s/\text{ft}^2 \text{ of collecting area}$$

At a typical 9 in. plate spacing the casing cost would be \$0.58/ft^2 of collecting area

$$\begin{array}{c}\text{Selling}\\ \text{price}\\ \text{impact}\end{array} = \frac{\left(\begin{array}{c}\text{Cost of}\\ \text{new material}\end{array} - \begin{array}{c}\text{Cost of}\\ \text{old material}\end{array}\right) M \quad \begin{array}{c}\text{Original overall}\\ \text{selling price}\end{array}}{\text{Original overall selling price}}$$

which gives us equations 6.34 and 6.35. Note that the value 0.58 will change significantly if a plate spacing other than 9 in. is chosen.

Thus, for a less than 5 percent increase in flange-to-flange cost, all the precipitator exposed wall sections can be increased by more than 25 percent to provide increased life under corrosive conditions. Section thickness increases that are greater than those just discussed would probably result in significant cost increases because of both increased material costs and necessary engineering design changes.

The impact of changing from mild steel to 304 stainless steel assuming material costs of \$1.63/lb for 18 gauge collecting plates, \$1.38/lb for the 3/16 in. casing, and a markup factor of 3 is as follows:

Plates:

$$I = \frac{\left\lfloor\left(\frac{2}{2} \times 1.63\right) - 0.9\right\rfloor 3 \quad 10}{10}$$

$$= 21.9 \text{ percent increase}$$

Casing:

$$I = \frac{\left\lfloor\left(\frac{7.66}{10} \times 1.38\right) - 0.58\right\rfloor 3 \quad 10}{10}$$

= 14.3 percent increase

To these material costs must be added extra fabrication labor and procurement costs that will increase the ESP flange-to-flange cost by a factor of 2 to 3. Note that a totally stainless steel collector would be much more expensive because the discharge electrodes, rappers, hangers, etc., would be also converted to stainless. The preceding equations can be used for other grades of stainless steel or other materials of construction by inserting material costs obtained from local vendors on a $/lb basis.

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